

# The Importance of Higher Twist Corrections in Polarized DIS

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## Abstract

The higher twist corrections  $h^N(x)/Q^2$  to the spin dependent proton and neutron  $g_1$  structure functions are extracted from the world data on  $g_1(x, Q^2)$  in a model independent way and found to be non-negligible. Their role in determining the polarized parton densities in the nucleon is discussed. It is also considered how the results are influenced by the recent JLab and HERMES/d inclusive DIS data.

*This talk was presented at DIS'2003 Workshop, St. Petersburg, 23-27 April, 2003.*

# 1 Introduction

Spurred on by the famous EMC experiment [1] at CERN in 1987, there has been a huge growth of interest in *polarized* DIS experiments which yield more refined information about the partonic structure of the nucleon, *i.e.*, how the nucleon spin is divided up among its constituents, quarks and gluons. Many experiments have been carried out at SLAC, CERN, DESY and JLab to measure the longitudinal ( $A_{\parallel}$ ) and transverse ( $A_{\perp}$ ) asymmetries and to extract from them the photon-nucleon asymmetries  $A_1(x, Q^2)$  and  $A_2(x, Q^2)$  as well as the nucleon spin-dependent structure functions  $g_1(x, Q^2)$  and  $g_2(x, Q^2)$ .

There is, however, an important difference between the kinematic regions of the unpolarized and polarized data sets. While in the unpolarized case we can cut the low  $Q^2$  and  $W^2$  data in order to eliminate the less known non-perturbative higher twist effects, it is impossible to perform such a procedure for the present data on the spin-dependent structure functions without losing too much information. So, to extract correctly the polarized parton densities from the experimental data a special attention should be paid to the higher twist (powers in  $1/Q^2$ ) corrections to the nucleon structure functions. Their role in determining the polarized parton densities in the nucleon using different approaches of QCD fits to the data is discussed in this talk. It is also considered how the results are influenced by the recent JLab [2] and HERMES/d [3] data.

## 2 QCD treatment of $g_1(x, Q^2)$

In QCD the spin structure function  $g_1$  can be written in the following form:

$$g_1(x, Q^2) = g_1(x, Q^2)_{\text{LT}} + g_1(x, Q^2)_{\text{HT}} , \quad (1)$$

where "LT" denotes the leading twist ( $\tau = 2$ ) contribution to  $g_1$ , while "HT" denotes the contribution to  $g_1$  arising from QCD operators of higher twist, namely  $\tau \geq 3$ . In (1) we have dropped the nucleon target label N. The HT power corrections (up to  $\mathcal{O}(1/Q^2)$  terms) can be divided in two parts:

$$g_1(x, Q^2)_{\text{HT}} = h(x, Q^2)/Q^2 + h^{\text{TMC}}(x, Q^2)/Q^2 , \quad (2)$$

where  $h^{\text{TMC}}(x, Q^2)$  are the exactly calculable [4] kinematic target mass corrections and  $h(x, Q^2)$  are the *dynamical* higher twist ( $\tau = 3$  and  $\tau = 4$ ) corrections to  $g_1$ , which are related to multi-parton correlations in the nucleon. The latter are non-perturbative

effects and cannot be calculated without using models.  $g_1(x, Q^2)_{\text{LT}}$  in (1) is the well known pQCD expression and in NLO has the form

$$g_1(x, Q^2)_{\text{pQCD}} = \frac{1}{2} \sum_q^{N_f} e_q^2 [(\Delta q + \Delta \bar{q}) \otimes (1 + \frac{\alpha_s(Q^2)}{2\pi} \delta C_q) + \frac{\alpha_s(Q^2)}{2\pi} \Delta G \otimes \frac{\delta C_G}{N_f}], \quad (3)$$

where  $\Delta q(x, Q^2)$ ,  $\Delta \bar{q}(x, Q^2)$  and  $\Delta G(x, Q^2)$  are quark, anti-quark and gluon polarized densities in the proton, which evolve in  $Q^2$  according to the spin-dependent NLO DGLAP equations.  $\delta C(x)_{q,G}$  are the NLO spin-dependent Wilson coefficient functions and the symbol  $\otimes$  denotes the usual convolution in Bjorken  $x$  space.  $N_f$  is the number of active flavors.

### 3 QCD fits to the data and the role of higher twists

Up to now, two approaches have been mainly used to extract the polarized parton densities (PPD) from the world polarized DIS data. According to the first [5, 6] the leading twist LO/NLO QCD expressions for the structure functions  $g_1^N$  and  $F_1^N$  have been used in order to confront the data on  $A_1(\approx g_1/F_1)$  and  $g_1/F_1$ . It was shown [6, 7] that in this case the extracted from the world data “effective” HT corrections  $h^{A_1}(x)$  to  $A_1$

$$A_1(x, Q^2) = (1 + \gamma^2) \frac{g_1(x, Q^2)_{\text{LT}}}{F_1(x, Q^2)_{\text{LT}}} + \frac{h^{A_1}(x)}{Q^2} \quad (4)$$

are negligible and consistent with zero within the errors,  $h^{A_1}(x) \approx 0$  (see Fig.1). This result has been confirmed independently in [5]. In Fig. 1 are also shown (open circles) our new results on the HT corrections to  $A_1$  including in the world data set [1, 8] the recent JLab [2] and HERMES [3] data on  $g_1/F_1$  for neutron and deuteron, respectively. As seen from Fig. 1, due to the much more precise JLab and HERMES new data, the HT corrections  $h^{A_1}(x)$  to  $A_1$  for the neutron and deuteron targets are much better determined now at large  $x$  and better consistent with zero in this kinematic region.

What follows from these results is that the higher twist corrections to  $g_1$  and  $F_1$  compensate each other in the ratio  $g_1/F_1$  and the PPD extracted this way are less sensitive to higher twist effects.

According to the second approach [9],  $g_1/F_1$  and  $A_1$  data have been fitted using phenomenological parametrizations of the experimental data for  $F_2(x, Q^2)$  and  $R(x, Q^2)$  ( $F_1$  has been replaced by the usually extracted from unpolarized DIS experiments  $F_2$  and  $R$ ). Note that such a procedure is equivalent to a fit to  $(g_1)_{\text{exp}}$ , but it is more precise

than the fit to the  $g_1$  data themselves actually presented by the experimental groups. The point is that most of the experimental data on  $g_1$  have been extracted from the  $A_1$  and  $g_1/F_1$  data using the additional assumption that the ratio  $g_1/F_1$  does not depend on  $Q^2$ . Also, different experimental groups have used *different* parametrizations for  $F_2$  and  $R$ .

If the second approach is applied to the data, the “effective higher twist” contribution  $h^{A_1}(x)/Q^2$  to  $A_1(g_1/F_1)$  is found [5] to be sizeable and important in the fit [the HT corrections to  $g_1$  cannot be compensate because the HT corrections to  $F_1$  ( $F_2$  and  $R$ ) are absorbed by the phenomenological parametrizations of the data on  $F_2$  and  $R$ ]. Therefore, to extract correctly the polarized parton densities from the  $g_1$  data, the HT corrections to  $g_1$  have to be taken into account. Note that a QCD fit to the data in this case, keeping in  $g_1(x, Q^2)_{QCD}$  only the leading-twist expression (as it was done in [9]), leads to some “effective” parton densities which involve in themselves the HT effects and therefore, are not quite correct.

Keeping in mind the discussion above we have analyzed the world data [1, 8] on inclusive polarized DIS taking into account the higher twist corrections to the nucleon structure function  $g_1^N(x, Q^2)$ . In our fit to the data we have used the following expressions for  $g_1/F_1$  and  $A_1$ :

$$\begin{aligned} \left[ \frac{g_1^N(x, Q^2)}{F_1^N(x, Q^2)} \right]_{exp} &\Leftrightarrow \frac{g_1^N(x, Q^2)_{LT} + h^N(x)/Q^2}{F_2^N(x, Q^2)_{exp}} 2x \frac{[1 + R(x, Q^2)_{exp}]}{(1 + \gamma^2)}, \\ A_1^N(x, Q^2)_{exp} &\Leftrightarrow \frac{g_1^N(x, Q^2)_{LT} + h^N(x)/Q^2}{F_2^N(x, Q^2)_{exp}} 2x [1 + R(x, Q^2)_{exp}], \end{aligned} \quad (5)$$

where  $g_1^N(x, Q^2)_{LT}$  is given by the leading twist expression (3) including the target mass corrections (N=p, n, d). The dynamical HT corrections  $h^N(x)$  in (5) are included and extracted in a *model independent way*. In our analysis their  $Q^2$  dependence is neglected. It is small and the accuracy of the present data does not allow to determine it. For the unpolarized structure functions  $F_2^N(x, Q^2)_{exp}$  and  $R(x, Q^2)_{exp}$  we have used the NMC parametrization [10] and the SLAC parametrization R<sub>1998</sub> [11], respectively. The details of our analysis are given in [12]. We have found that the fit to the data is significantly improved when the higher twist corrections to  $g_1$  are included in the analysis, especially in the LO QCD case. We have also found that the size of the HT corrections to  $g_1$  is *not* negligible and their shape depends on the target (see Fig. 2). In Fig. 2 are also presented (open circles) our new results on the HT corrections to  $g_1$  including in the world data set the recent JLab [2] and HERMES [3] data. As seen from Fig. 2, the higher twist corrections to the neutron spin structure functions in the large  $x$  region are much better determined now. It was also shown (see Fig. 3) that

the NLO QCD polarized PD( $g_1^{\text{LT}} + \text{HT}$ ) determined from the data on  $g_1$ , including higher twist effects, are in good agreement with the polarized PD( $g_1^{\text{NLO}}/F_1^{\text{NLO}}$ ) found earlier from our analysis [6] of the data on  $g_1/F_1$  and  $A_1$  using for the structure functions  $g_1$  and  $F_1$  only their *leading* twist expressions in NLO QCD. This observation confirms once more that the higher twist corrections to  $g_1/F_1$  and  $A_1$  are negligible, so that in the analysis of  $g_1/F_1$  and  $A_1$  data it is enough to account only for the leading twist of the structure functions  $g_1$  and  $F_1$ . On the other hand, in fits to the  $g_1$  data themselves the higher twist contribution to  $g_1$  must be taken into account. The latter is especially important for the LO QCD analysis of the inclusive and SIDIS data.

This research was supported by the JINR-Bulgaria Collaborative Grant, by the RFBR (No 02-01-00601, 03-02-16816), INTAS 2000 (No 587) and by the Bulgarian National Science Foundation under Contract Ph-1010.

## References

- [1] EMC, J. Ashman *et al.*, Phys. Lett. **B206** (1988) 364; Nucl. Phys. **B328** (1989) 1.
- [2] JLab, X. Zheng *et al.*, nucl-ex/0308011.
- [3] C. Weiskopf, DESY, Thesis 02-043, 2002.
- [4] J. Blumlein and A. Tkabladze, Nucl. Phys. Proc.Suppl. **79** (1999) 541; S. Simula, M. Osipenko, G. Ricco, M. Taiuti, Phys. Rev. D **65** (2002) 034017.
- [5] M. Glück, E. Reya, M. Stratmann, W. Vogelsang, Phys. Rev. D **63** (2001) 094005.
- [6] E. Leader, A.V. Sidorov, D.B. Stamenov, Eur. Phys. J. **C23** (2002) 479.
- [7] E. Leader, A.V. Sidorov, D.B. Stamenov, in *Particle Physics at the Start of the New Millennium*, edited by A.I. Studenikin, World Scientific, Singapore, May 2001, p. 76. (*Proceedings of the 9th Lomonosov Conference on Elementary Particle Physics, Moscow, Russia, 20-26 Sep 1999*).
- [8] SLAC E142 Coll., P.L. Anthony *et al.*, Phys. Rev. D **54** (1996) 6620; SLAC/E154 Coll., K. Abe *et al.*, Phys. Rev. Lett. **79** (1997) 26; SMC, B. Adeva *et al.*, Phys. Rev. D **58** (1998) 112001; HERMES, K. Ackerstaff *et al.*, Phys. Lett. **B404** (1997) 383; *ibid* **B442** (1998) 484; SLAC E143 Coll., K. Abe *et al.*, Phys. Rev. D **58** (1998)

- 112003; SLAC/E155 Coll., P.L. Anthony *et al.*, Phys. Lett. **B463** (1999) 339, *ibid* **B493** (2000) 19.
- [9] SMC, B. Adeva, et al., Phys. Rev. D **58** (1998) 112002; J. Blumlein and H. Bottcher, Nucl. Phys. **B636** (2002) 225.
- [10] NMC Coll., M. Arneodo *et al.*, Phys. Lett. **B364** (1995) 107.
- [11] E143 Coll., K. Abe *et al.*, Phys. Lett. **B452** (1999) 194.
- [12] E. Leader, A.V. Sidorov, D.B. Stamenov, Phys. Rev. D **67** (2003) 074017.

## Figure Captions

**Fig.1.** Effective higher twist contribution  $h^{A_1}(x)$  to the spin asymmetry  $A_1^N(x, Q^2)$  extracted from the data.

**Fig. 2.** Higher twist corrections to the proton and neutron  $g_1$  structure functions extracted from the data on  $g_1$  in the NLO QCD approximation for  $g_1(x, Q^2)_{\text{LT}}$ .

**Fig. 3.** NLO(JET) polarized parton densities  $\text{PD}(g_1^{\text{NLO}} + \text{HT})$  (solid curves) together with error bands compared to  $\text{PD}(g_1^{\text{NLO}}/F_1^{\text{NLO}})$  (dashed curves) at  $Q^2 = 1 \text{ GeV}^2$ . The error bands represent the total errors.

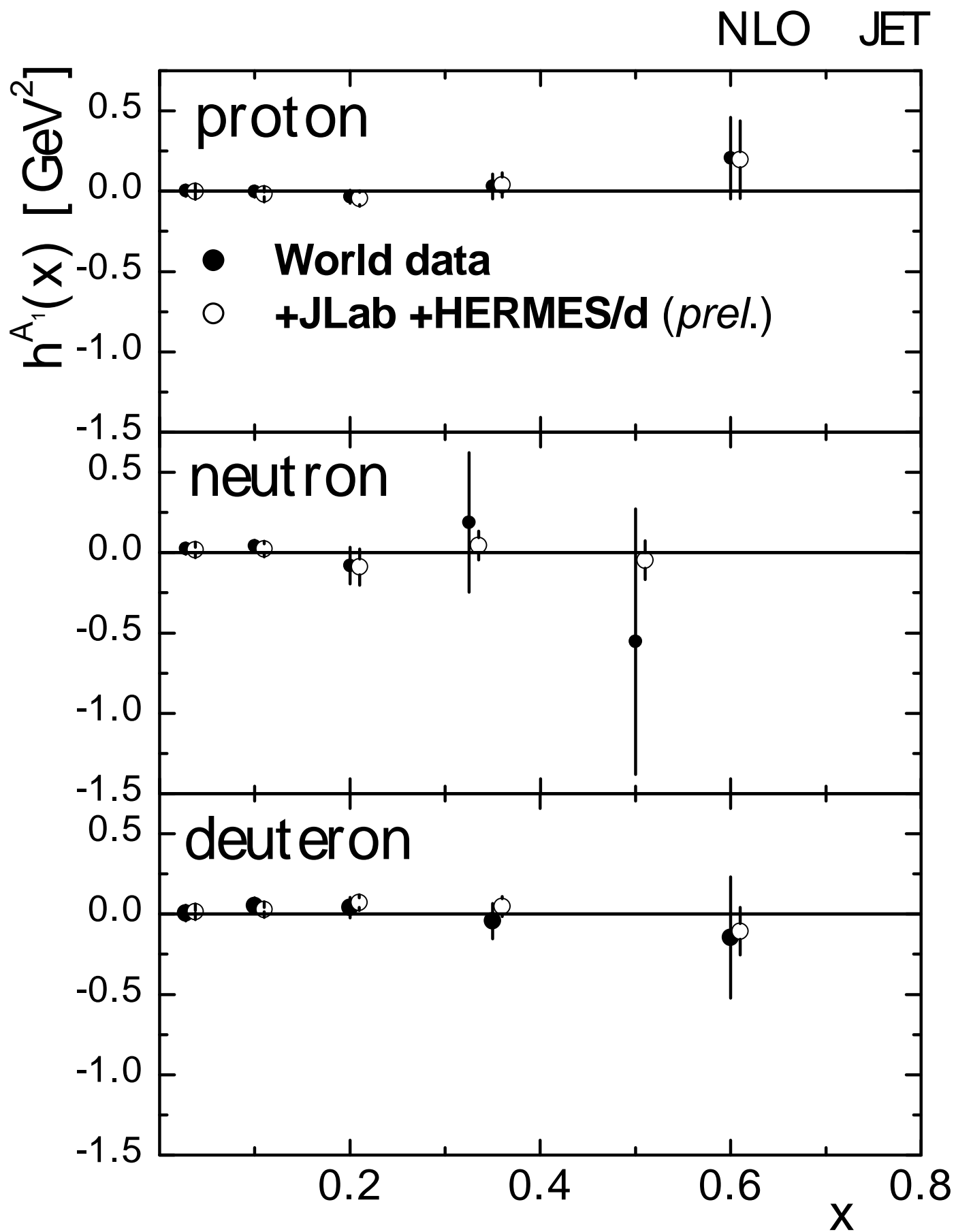


Fig. 1



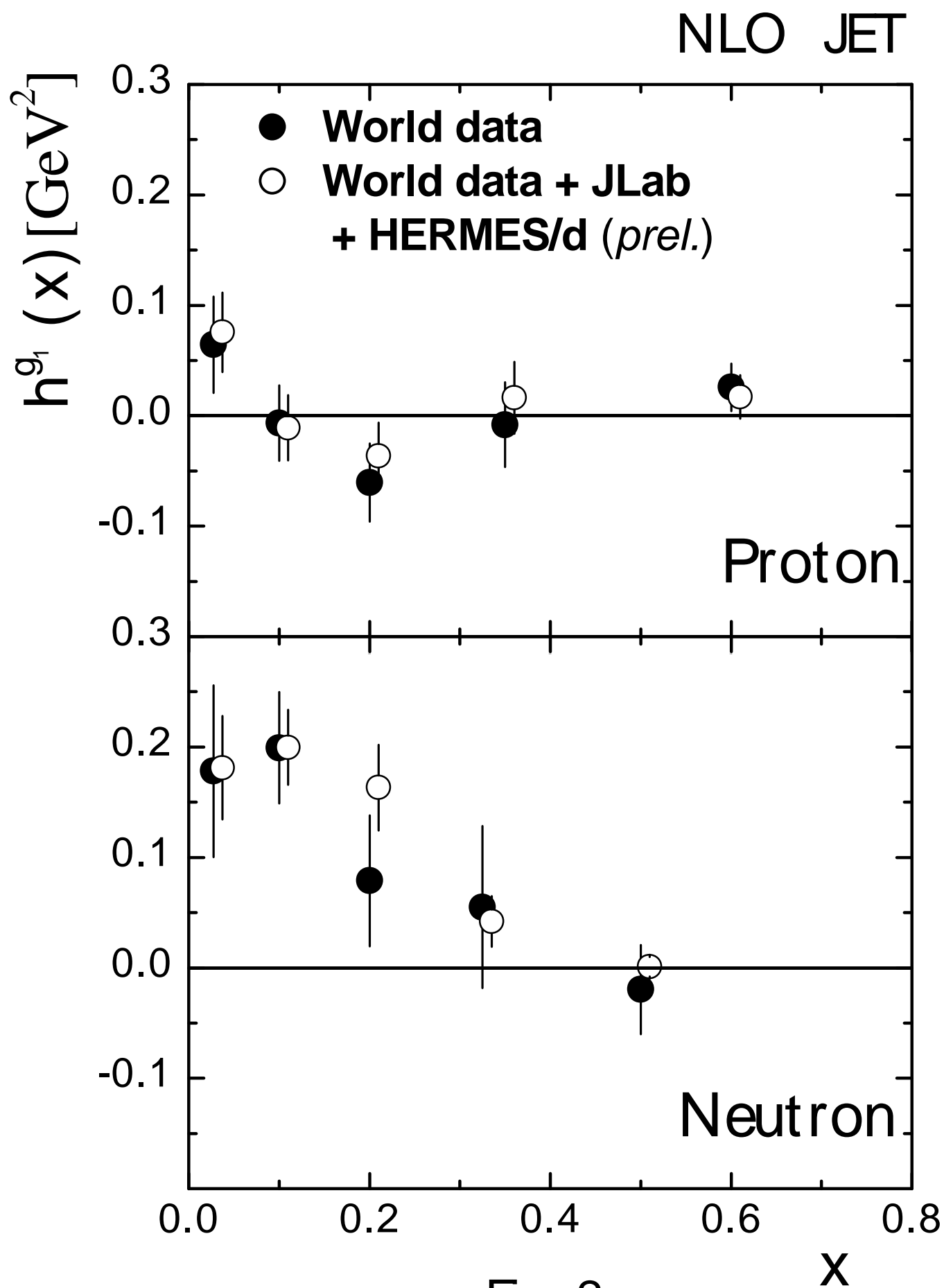


Fig. 2

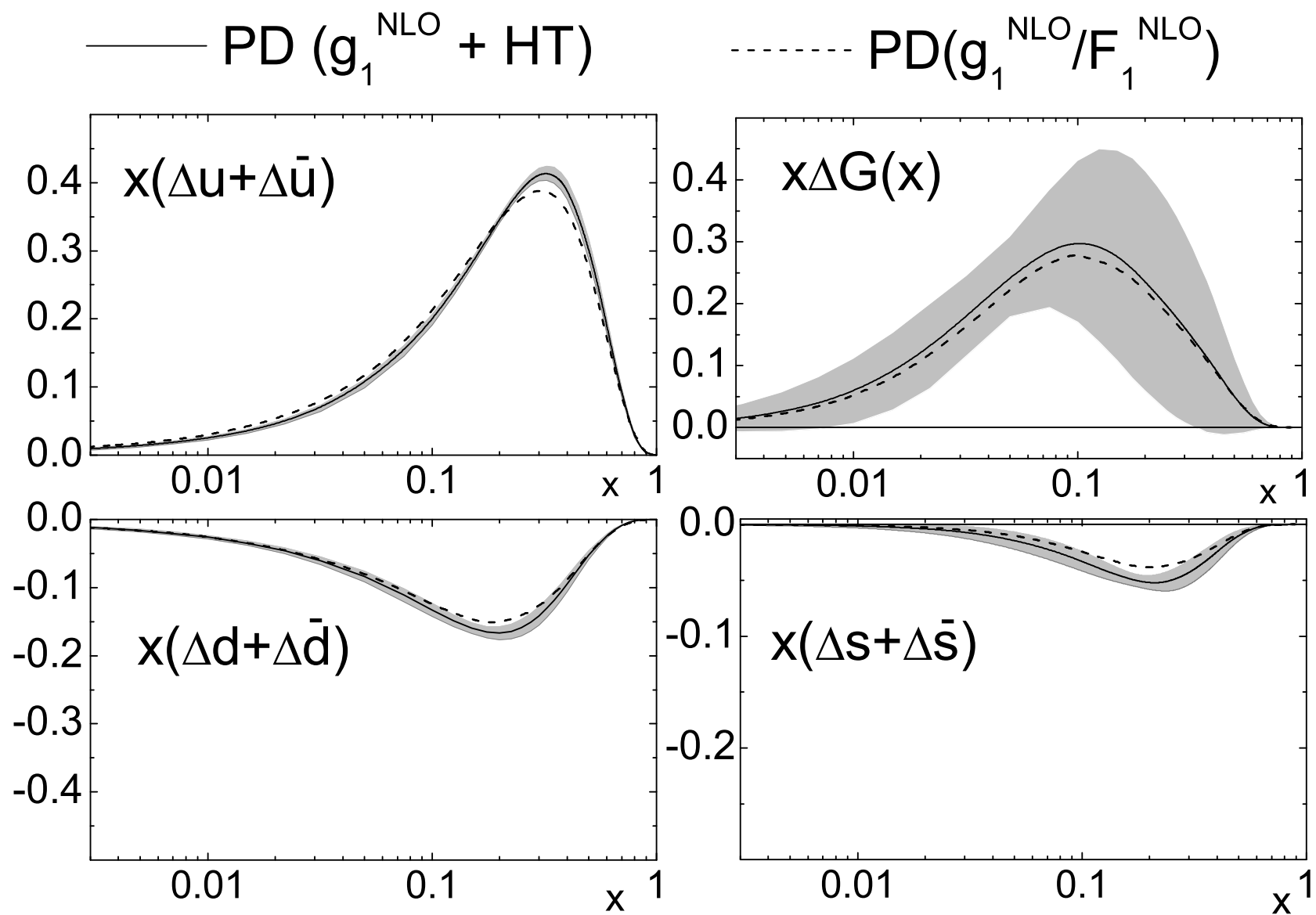


Fig. 3